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2
3 TRAJECTORY MATCHED PASSIVE DETECTION SYSTEM
4

5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 governmental purposes without the payment of any royalties
9 thereon or therefor.
10

11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 This invention is directed toward target detection systems,
14 and more particularly, to a passive target detection system and
15 method which takes into consideration the beam pattern of the
16 detection system sonar array as well as the non-linear rate at
17 which tonals progress due to Doppler effect and movement of the
18 detection system carrier.

19 (2) Description of the Prior Art

20 The prior art includes both passive and active underwater
21 detection systems. Since active systems can be detected by a
22 target or enemy due to a radiated ping from the source, it is
23 preferred that passive detection systems be used. For passive
24 systems, a signal is detected from the target and used to direct
25 a detection system carrier, such as a torpedo, to the target.

1 Several prior art patents discuss both passive and active
2 target detection systems. However, each of the following patents
3 suffers from one or more disadvantages which limits their ability
4 to effectively and accurately detect targets.

5 U.S. Patent No. 4,975,886 to Ellingson discloses a detecting
6 and ranging system which uses hydrophones for detecting
7 compressional waves emitted by a sound source. While a passive
8 system is disclosed, it fails to take into account Doppler
9 effects and the pattern of motion of the system carrier which
10 eventually is to be directed to the target. Accordingly, the
11 accuracy of the system suffers.

12 U.S. Patent No. 5,341,347 to Ludwig discloses an electro-
13 acoustic target searching system for torpedoes. The system
14 comprises a receiving transducer means capable of receiving
15 signals at a first, second or third frequency based upon the
16 magnitude of the signal. Although a passive system is disclosed,
17 the system is only capable of receiving and processing signals at
18 one frequency at a time.

19 U.S. Patent No. 5,251,185 to Baggenstoss discloses a sonar
20 signal processor and display system. This system combines the
21 use of both coherent and incoherent signal processors. In
22 addition to a conventionally used matched filter detection
23 processor, an incoherent signal processor, comprising a cross
24 range energy filter and a down range energy filter, is used. The
25 pattern of the system carrier and Doppler effects are apparently

1 not taken into account in determining the coordinates of targets,
2 and therefore, a degree of detection accuracy is lost.

3 U.S. Patent No. 3,798,590 to Jacobson et al. discloses a
4 signal processing apparatus including Doppler dispersion
5 correction means in connection with active sonar return signal
6 processing. The apparatus includes a signal generator providing
7 an inverse replica of the signal which is shifted upwardly in
8 frequency and is transmitted as a sonar signal.

9 Additional patents of interest are U.S. Patent No. 5,251,186
10 to Lockwood disclosing a preprocessor and adaptive beam former
11 for linear frequency modulation active signal; U.S Patent No.
12 4,754,282 to Edelblute et al. disclosing an improved data
13 analysis system; U.S. Patent No. 5,157,615 to Brodegard et al.
14 disclosing an aircraft traffic alert and collision avoidance
15 device; U.S. Patent No. 4,549,184 to Boles et al. disclosing a
16 moving target ordinance control; U.S. Patent No. 5,245,587 to
17 Hutson disclosing a multi-dimensional signal processing and
18 display system; and U.S. Patent No. 5,337,053 to Dwyer disclosing
19 a method and apparatus for classifying targets.

20 While each of these patents disclose systems, methods or
21 devices directed to target detection, none of these patents
22 disclose an all encompassing passive target detection system
23 which takes into account the beam pattern of the detection system
24 sonar array and non-linear rate that tonals progress due to
25 Doppler effects as well as movement of the system carrier.

1 In currently known target detection systems, such as those
2 discussed above, the models for generating matching signals
3 simplify to a linear model, consider only one tonal or frequency,
4 and/or neglect the beam pattern of the detection system tonal
5 array, thereby leading to reduced accuracy in subsequent
6 matching. Accordingly, error in estimating target position
7 occurs.

8 There exists a need, therefore, for a passive target
9 detection system which takes into account the beam pattern of the
10 detection system sonar array, the non-linear rate at which tonals
11 progress due to Doppler effects and the movement of the detection
12 system, which utilizes a plurality of tonals and which operates
13 over a wide frequency band.

14 15 SUMMARY OF THE INVENTION

16 The primary object of this invention is to provide a passive
17 target detection system having improved target modeling ability.

18 Another object of this invention is to provide a passive
19 target detection system which takes into account Doppler effects
20 and motion of the detection system carrier in modeling target
21 signals.

22 Yet another object of this invention is to provide a passive
23 target detection system which operates over a wide frequency band
24 and thereby provides enhanced detection accuracy.

25 A further object of this invention is to provide a process
26 for passive target detection.

1 These and other objects and advantages disclosed herein are
2 achieved by the passive target detection system of the present
3 invention. The system is preferably used with a moving target
4 detection system carrier. The system comprises means for
5 postulating modeled target signals based upon a number of factors
6 including at least one factor selected from the group consisting
7 of signal beam pattern, frequency, non-linear signal progression
8 and carrier movement; means for receiving signals from a target;
9 and means for comparing said signals with said modeled target
10 signals for determining location of said target.

11 In further accordance with the invention, a process for
12 detecting a target with a passive target detection system and a
13 moving target detection system carrier is provided which method
14 comprises the steps of postulating modeled target signals based
15 upon at least one factor selected from the group consisting of
16 signal beam pattern, frequency, non-linear signal progression and
17 carrier movement; receiving signals from a target; and comparing
18 said signals with said modeled target signals for determining
19 location of said target.

20 21 BRIEF DESCRIPTION OF THE DRAWINGS

22 A more complete understanding of the details of the system
23 and process of the present invention are set forth in the
24 following description and the accompanying drawings in which like
25 reference numerals depict like elements and wherein:

1 FIG. 1 is an overall schematic view of the passive target
2 detection system in use with a system carrier and in accordance
3 with the principles of the present invention;

4 FIG. 1a is a schematic view of a system in accordance with
5 the invention; and

6 FIG. 2 is a schematic view of the process of the passive
7 target detection system in accordance with the principals of the
8 present invention.

9
10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

11 Referring now to the drawings in detail, there is shown in
12 FIGS. 1 and 1a, a schematic diagram of a passive detection system
13 in accordance with the principals of the present invention, which
14 is designated generally as 10. System 10 generally includes an
15 array of receivers 12, a processor 14 for postulating or modeling
16 target signals, and a plurality of matched filters 16 operatively
17 associated with processor 14.

18 Signals of measurable frequencies are received by the array
19 of receivers 12 from a distant target 18, which array of
20 receivers 12 are positioned on a detection system carrier 20 as
21 indicated in the diagram of FIGS. 1 and 1a, for example, a
22 torpedo or submarine. In a typical situation, the carrier 20
23 moves in a pattern relative to the target, for example in a
24 circular pattern as shown by the dotted line representation of
25 the carrier 20, while signals are received by the array of
26 receivers 12. The pattern 22 is preferably circular although

1 other patterns can be used, for example, a spiral pattern. Data
2 is calculated and analyzed in accordance with the process set
3 forth below via processor 14, which may be hardware, software
4 modules, or a combination of hardware and software. From the
5 data and typically in conjunction with a guidance system or the
6 like, a torpedo, submarine or other device requiring target
7 detection can passively detect the location of a target.

8 In accordance with the invention, system 10 serves to
9 postulate a series of modeled target signals, and to receive
10 signals from target 18, whereby received signals are compared to
11 the modeled signals so as to determine the presence and location
12 of a target 18. According to the invention, and advantageously,
13 system 10 serves to model target signals taking into account at
14 least one and preferably a number of factors selected from the
15 group consisting of signal beam pattern, frequency, non-linear
16 signal progression and movement of carrier 20.

17 System 10 in accordance with the invention is preferably
18 adapted to postulate matched filters for a series of k signals
19 corresponding to or spaced over a range of signal frequencies or
20 tonals received by receivers 12. It is preferred to process a
21 series of tonals distributed over the entire frequency range,
22 however, a subset or non-continuous set of tonals may be
23 processed in accordance with the invention. By considering the
24 foregoing factors in signal postulating, and performing matched
25 filters for a series of signal frequencies or tonals, system 10
26 in accordance with the present invention serves to provide

1 enhanced accuracy of signal modeling and, thereby, more accurate
2 detection, location and classification of targets.

3 Referring to FIG. 2, the process of the present invention
4 will now be further described. FIG. 2 shows, schematically, a
5 signal correlator 100, an accumulator 110, a filter 120 and
6 matched filters 130 which are operatively associated and serve in
7 accordance with the present invention to process data points
8 received by receivers 12 and provide indication as to detection
9 of a target. Processor or accumulator 140 serves to further
10 process or "post process" data from filters 120, 130 so as to
11 determine the location of a particular target.

12 Referring to correlator 100, receivers 12 may typically
13 receive a plurality of signal elements, which are formed by
14 system 10 into beams, typically through right and left apertures
15 (not shown) of carrier 20. The corresponding left and right
16 beams contain time series data points from the sonar array of the
17 carrier. The data is combined to generate a single received
18 signal, for example by cross correlating the data streams point
19 by point. Cross correlation between left and right channels can
20 for example be accomplished by conjugating one data stream and
21 multiplying in accordance with standard signal processing
22 techniques. Receivers 12 and processor 14 are preferably adapted
23 so as to provide the received signal in batches of data points
24 selected to equal the beam width for that particular sonar array.
25 This advantageously allows for matched filters to be run at each
26 tonal or signal frequency selected within the beam width.

1 As set forth above, system 10 postulates modeled target
2 signals against which received signals are correlated so as to
3 obtain data which is indicative of target location and other
4 useful information.

5 System 10 in accordance with the present invention models
6 signals as follows. Signals R are modeled as the sum over k of k
7 tonals (R_{kk}), and can be determined as follows:

$$8 \quad R = \sum R_{kk} = \sum A_k^2 * e^{-i*2\pi*f_k\tau} \quad (1)$$

9 wherein A_k^2 is power and is given by

$$10 \quad A_k^2 = b^2(\theta_0 - \theta) ; \quad (2)$$

11 f_k is the frequency of each tonal and is given by

$$12 \quad f_k = f_{0,k} * (1 + V_t/c * \cos(\theta_0 - \theta)) ; \quad (3)$$

13 τ is correlation delay (sec) and is given by

$$14 \quad \tau = d/c * \sin(\theta_0 - \theta) \quad (4)$$

15 and wherein: b is a batch length (L_b) by 1 vector of beam
16 weights; θ is the carrier azimuth heading; θ_0 is the carrier
17 heading at middle of current batch; $f_{0,k}$ is the k^{th} tonal's base
18 frequency (Hz); V_t is the carrier velocity (ft/sec); c is the
19 speed of sound (ft/sec); and d is the aperture spacing (ft).

1 As set forth above, the motion of carrier 20 carrying system
2 10 is taken into account in accordance with the present invention
3 so that noise and other extraneous signals generated by carrier
4 20 can be detected and removed from consideration. Thus, carrier
5 azimuth heading θ is preferably determined as a function of turn
6 rate as follows:

$$7 \qquad \qquad \qquad \theta = \zeta * t \qquad \qquad \qquad (5)$$

8 wherein ζ is carrier turn rate in degrees per second and t is
9 time (sec).

10 Carrier heading (θ_0) in the middle of the current batch is
11 preferably determined as follows:

$$12 \qquad \qquad \qquad \theta_0 = \theta - \left(\frac{B.W.}{2} \right) \qquad \qquad \qquad (6)$$

13 wherein B.W. is the beam width in degrees (adaptation parameter),
14 and θ is the carrier heading at the end of the batch.

15 Modeling signals in accordance with the above provides R,
16 the resulting modeled target correlation, which is used in
17 subsequent matched filter analysis so as to determine the
18 position of a target as desired. This modeling is preferably
19 carried out by processor 14 as hardware designed for the purpose
20 or operating software or code 23 (FIG. 1a) for the purpose, or
21 software modules, or combinations of hardware and software as
22 desired.

1 Samples of data points are gathered for processing in
2 batches over batch lengths (L_b) as follows:

$$L_b = \frac{B.W.}{\zeta} * f_s \quad (7)$$

4 wherein f_s = sampling rate in samples per second.

5 As set forth above, it is preferred that the system and
6 process in accordance with the present invention receive signals
7 at different tonals distributed over the band width for receivers
8 12, and that target signals be modeled at each of these tonals.
9 Since each term progresses at a different electrical phase rate
10 even when the terms may be coming from the same angle, the use of
11 matched filters at more than one tonal serves to greatly enhance
12 the accuracy of detection in accordance with the present
13 invention.

14 Also as set forth above, a further advantage of the present
15 invention is the consideration of the movement rate of carrier 20
16 in the process of modeling signals. Considering carrier movement
17 during modeling signals is advantageous in accordance with the
18 invention since this consideration allows background noise and
19 other non-target signals which may be generated by carrier 20 to
20 be eliminated since such signals will have the same movement
21 component as carrier 20. Thus, by filtering for carrier
22 movement, attention can be and is focused on signals meeting
23 other filters and which are relatively stationary with respect to
24 carrier 20.

1 Finally, and referring back to FIG. 1, the signal modeling
2 process set forth above is further advantageous in that beam
3 patterns are more accurately modeled by avoiding substantially
4 square beam pattern estimates of the prior art processes
5 discussed above. In FIG. 1, the beam pattern is more accurately
6 modeled as shown, with points P1, P2, P3 being locations at which
7 source or target 18 appears along a particular beam pattern. As
8 shown in FIG. 1, angle α is the degree of coverage of the beam
9 pattern for a particular circle segment, and also equals the arc
10 of a circle traversed corresponding to the beam pattern.
11 According to the invention, a number of batches of points may be
12 received by receivers 12 for various lengths L_b along the
13 perimeter of carrier pattern 22. Thus, as shown in FIG. 1,
14 lengths L_{b1} , L_{b2} and L_{b3} would correspond to three batches of
15 points.

16 Referring back to FIG. 2, accumulator 110 gathers signals
17 from correlator 100 for processing in batches which equal one
18 traversal through the beam pattern. Each batch represents an
19 entire sweep of a proposed target through the beam pattern of the
20 array, wherein the sweep preferably includes a section of
21 approximately 45° as indicated by angle α in FIG. 1.

22 At filter 120, received signals and modeled target signals
23 are then windowed by a normalized beam pattern, preferably in
24 accordance with the following equation:

$$x(i) = r(i) * b(i)^2 \quad (8)$$

wherein: x is the length (L_b) by 1 vector of weighted correlation samples; r is the length (L_b) by 1 vector of correlation samples; and b is the length (L_b) by 1 vector of beam weights.

Still referring to FIG. 2, data from filter 120 is then passed to a comparison unit with matched filters 130 wherein received signals or data streams, after having been gathered into batches, are matched to a series of modeled signals as represented by the following:

$$\ell_k = x^t * h_k \quad (9)$$

wherein ℓ_k is the k^{th} test statistic, or statistic for the k^{th} tonal; the superscript t indicates the hermitian transpose; and h_k is the match filter for the k^{th} tonal.

The matched filter sinusoid (h_k) with frequency $f_{0,k}$ modulated in a non-linear fashion can then be determined as follows:

$$h_k = \exp (-i * 2\pi * f_{0,k} * [1 + V_t/c * \cos\psi] * d/c * \sin\psi) \quad (10)$$

wherein $f_{0,k}$ is the k^{th} tonal base frequency (Hz); and ψ is the angle traversed for the data points in a particular batch, and can be determined as follows:

$$\psi = B.W. * (-1/2 + 1/L_b, -1/2 + 2/L_b, \dots, 0, \dots, 1/2)^t \quad (11)$$

1 It should be apparent that by modulating each frequency of
2 the signals or data stream with processor 14 performing steps as
3 above, that modulation is carried out in a non-linear fashion
4 such that each filter yields a complex test statistic which
5 represents the degree of matching between the signal received by
6 receivers 12 and the postulated or modeled target signals
7 prepared by system 10 as set forth above. Preferably, postulated
8 frequencies are preselected while actual responses are calculated
9 on line since such responses are dependent upon carrier turn
10 rate.

11 Accumulator 140 preferably stores test statistics for post
12 processing for further analysis in connection with target
13 identification and location. Post processing may be carried out
14 so as to determine a total test statistic or sum (ℓ) as follows:

$$\ell = \sum |\ell_i|^2 \quad (12)$$

16 wherein ℓ_i is the test statistic for a batch.

17 Also, real and imaginary parts of the coherent sum can be
18 determined as follows:

$$\ell_{re} = \sum \text{Re}(\ell_i) \quad (13)$$

$$\ell_{im} = \sum \text{Im}(\ell_i) \quad (14)$$

21 wherein $\text{Re}(\ell_i)$, $\text{Im}(\ell_i)$ are the real and imaginary parts of the
22 coherent sum.

1 Test statistics are preferably stored in a computer memory
2 26 associated with processor 14, as illustrated in FIGS. 1a and
3 2. Each test statistic includes several parts as set forth
4 above, that is the accumulated or total power ℓ the accumulated
5 real part ℓ_{re} and the accumulated imaginary part ℓ_{im} which are
6 calculated as set forth above on a batch by batch basis.

7 Of course, other accurate test statistics may be postulated.
8 However, batch power is the primary test statistic determined by
9 processor 14 and/or code 23. Batch power is used for target
10 detection and is viewed as a time series by linking the batches.
11 Batch power can be thresholded by an adaptive normalizer included
12 with matched filter 16 which need not be causal, for providing an
13 adaptive signal threshold after the pattern is complete, for use
14 in predicting future values for estimating or postulating the
15 signal. Test statistics stored in computer memory 26 are
16 preferably used for determining the adaptive signal threshold.

17 In accordance with the foregoing, it should be apparent that
18 a system and process have been provided for passive target
19 detection having improved target modeling ability and,
20 accordingly, improved accuracy. The system and process of the
21 present invention model target signals based upon a number of
22 factors including signal beam pattern, non-linear rate of
23 progression of a tonal due to Doppler effects and torpedo
24 movement, and the like. Furthermore, signals are modeled for a
25 plurality of tonals distributed over a wide band width, thereby

1 providing further enhanced accuracy of the system and process of
2 the present invention.

3 The primary advantage of this invention is that a passive
4 target detection system is provided having improved target signal
5 modeling ability. Another advantage of this invention is that a
6 passive target detection system is provided which takes into
7 account both Doppler effects and system carrier patterns in
8 determining position of a target. Another advantage of this
9 invention is that a passive target detection system is provided
10 including a receiver for receiving signals from a passive target
11 which system takes into account the motion of the receiver for
12 enhancing signal detection. Still another advantage of this
13 invention is that a passive target detection system is provided
14 which is capable of non causal operation. Still another
15 advantage of this invention is that a passive target detection
16 system is provided which preferably stores at least one cycle of
17 detected parameters for more accurately determining the location
18 of the target.

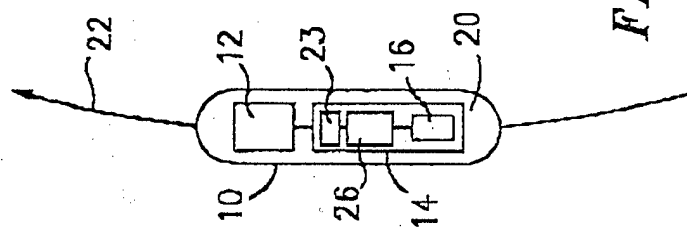
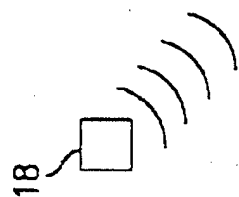
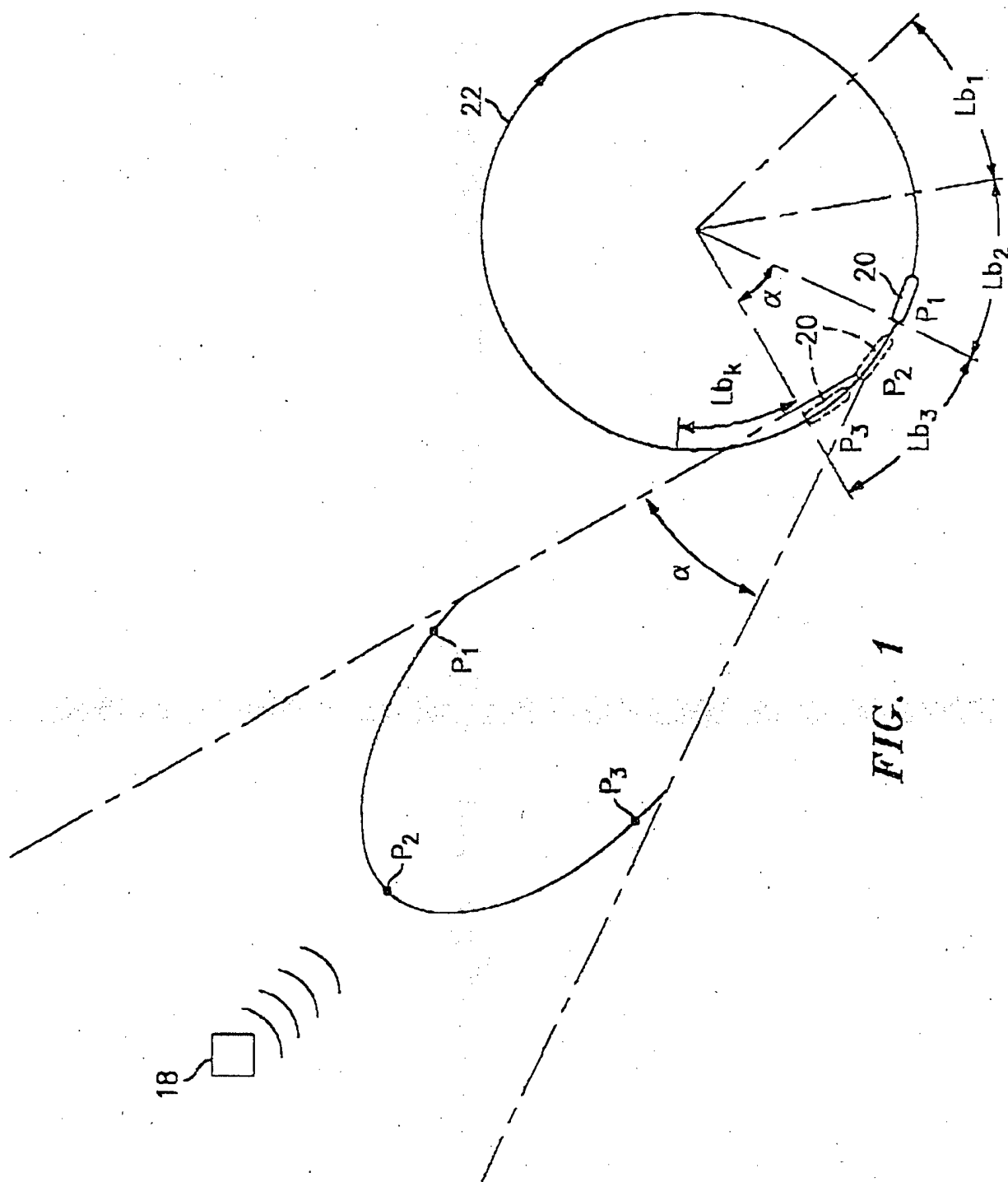
19 It is apparent that there has been provided in accordance
20 with this invention a trajectory matched passive detection system
21 and process which fully satisfies the objects, means, and
22 advantages set forth hereinbefore. While the invention has been
23 described in combination with specific embodiments thereof, it is
24 evident that many alternatives, modifications, and variations
25 will be apparent to those skilled in the art in light of the
26 foregoing description. Accordingly, it is intended to embrace

1 all such alternatives, modifications, and variations.

2

ABSTRACT OF THE DISCLOSURE

A passive target detection system for use with a moving platform which includes a module for postulating modeled target signals based upon a number of factors including at least one factor selected from the group consisting of signal beam pattern, frequency, non-linear signal progression and carrier movement; a receiver for receiving signals from a target; and a comparison unit for comparing the signals with the modeled target signals, for determining location of the target.



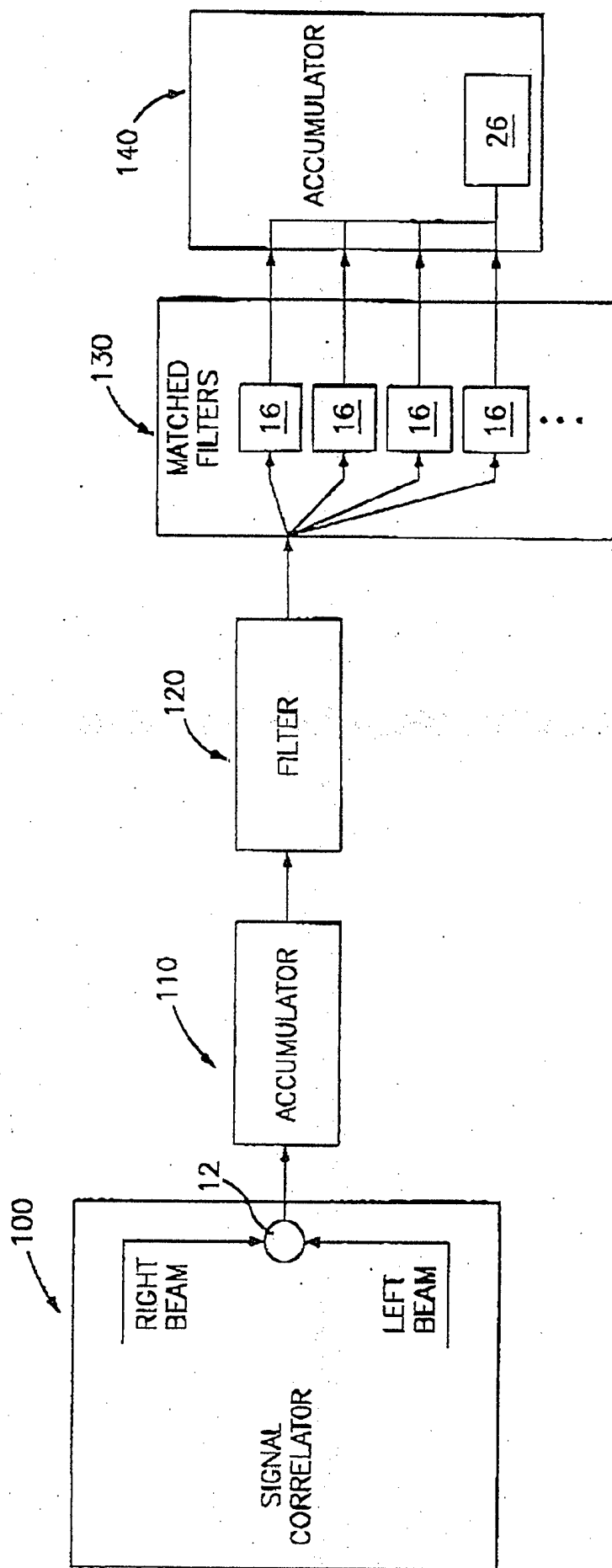


FIG. 2